

Probing top quark anomalous magnetic moment at LHC

LHCphenOnet Mid-Term Meeting

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20 September 2012

work in progress in collaboration with:
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Outline

1 Introduction

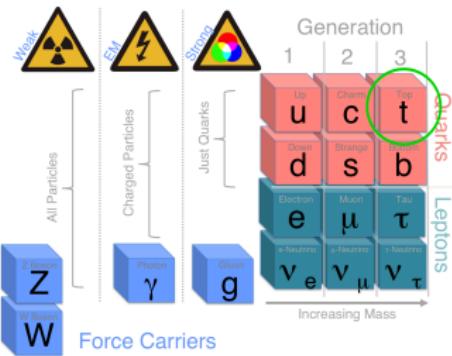
2 Form Factors

3 $t\bar{t}\gamma$

4 Single Top+ γ

5 Conclusion

Top Quark



- The heaviest known fundamental particle, discovered at the Tevatron in 1995.
- Top does not produce bound states: $\tau_t \approx 5 \cdot 10^{-25} s < \tau_{\text{had}} \approx 3 \cdot 10^{-24}$.
- Spin correlation of decay products.
- $m_t = 173.5 \text{ GeV}$, top quark is an excellent probe of the mechanism that breaks the EW gauge symmetry.

Top Quark

- New physics connected with EWSB may thus be found first in top quark precision observables.
- A possible signal of NP are deviations of the $t\bar{t}\gamma$, $t\bar{t}Z$ and $t\bar{b}W$ couplings from the values predicted by the SM.
- Single-top production provides a means of directly measuring $|V_{tb}|$.

CMS $|V_{tb}| = 1.04 \pm 0.09(\text{exp}) \pm 0.02(\text{th})$ CMS PAS TOP-11-021

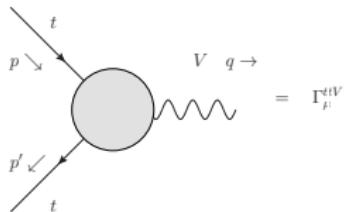
ATLAS $|V_{tb}| = 1.04^{+0.14}_{-0.13}$ CERN-PH-EP-2012-082

- $t\bar{t}Z$ vector and axial couplings are rather tightly but indirectly constrained by LEP data. Baur & al. PRD 71 (2005) 54013

How can we measure the $t\bar{t}\gamma$ coupling at LHC?



General $t\bar{t}\gamma$ Couplings



The most general Lorentz-invariant vertex function describing the interaction of a vector boson V with two on-shell top quarks can be written as:

$$\Gamma_\mu^{ttV} = ie \left\{ \gamma_\mu [F_{1V}^V(q^2) + \gamma_5 F_{1A}^V(q^2)] + \frac{\sigma_{\mu\nu}}{2m_t} q^\nu [iF_{2V}^V(q^2) + \gamma_5 F_{2A}^V(q^2)] \right\}$$

Taking $V = \gamma$, in the limit $q^2 \rightarrow 0$

$$F_{1V}^\gamma(0) = Q_t = \frac{2}{3}, \quad F_{2V}^\gamma(0) = Q_t \frac{g - 2}{2}, \quad F_{2A}^\gamma(0) = \frac{2m_t}{e} d_t^\gamma.$$



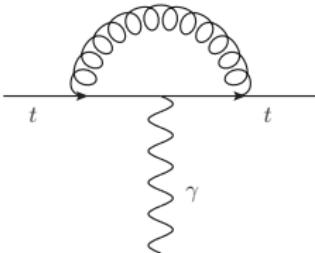
Anomalous Magnetic Moment

The magnetic moment of particle of mass m and charge q :

$$\vec{\mu} = g \frac{q}{2m} \vec{S}.$$

For a spin-1/2 fermion $g = 2$. The g -factor is modified by quantum correction:

$$a_t = \frac{g - 2}{2} = \frac{F_{2V}^\gamma(0)}{Q_t}$$



$$a_t = \frac{\alpha_s}{2\pi} C_F + \left(\frac{\alpha_s}{2\pi}\right)^2 a_t^{(2l)} + \dots$$

$$Q_t a_t^{SM}(\mu = m_t) = 2.15 \cdot 10^{-2},$$

A.G. Grozin, P. Marquard,

J.H. Piclum, M. Staeinhauser NPB 789 (2008) 277-293

Effective Lagrangian Approach

Effective operators included in the Lagrangian:

$$\begin{aligned}\mathcal{L}_{\text{eff}} = & e A^\mu \bar{t} [\gamma_\mu (\Delta F_{1V} + \Delta F_{1A} \gamma_5)] t \\ & + \frac{e}{4m_t} F_{\mu\nu} \bar{t} [\sigma^{\mu\nu} (\Delta F_{2V} - i \Delta F_{2A} \gamma_5)] t,\end{aligned}$$

where the coefficients $\Delta F_{iV,A}$ parametrize any deviation from the SM tree level values.

- $t\bar{t}\gamma$ and single-top+ γ production at LHC as a tool to constrain $\Delta F_{iV,A}$ (in particular a_t).
- Which observable is more suited to unveil any SM deviations?
- What quantitative bounds can be derived on the anomalous $t\bar{t}\gamma$ couplings?



$t\bar{t}\gamma$ at LHC

Study of the process $pp \rightarrow t\bar{t}\gamma$ at LHC@14TeV

U. Baur, A. Juste, L.H. Orr, D. RainWater PLD 71 (2005) 54013

- Process considered: $pp \rightarrow \gamma \ell \nu_\ell b\bar{b}jj$ with $\ell = e, \mu$.
- Minimal detector effects via Gaussian smearing of parton momenta. $\epsilon_b^2 = 40\%$ assumed.
- Main source of background is $t\bar{t}j$.

Process	LHC
signal	81.7 fb
$t\bar{t}j \quad P_{j \rightarrow \gamma} = 1/1600$	45.7 fb



Sensitivity Bounds

Sensitivities achievable at 68.3% CL for anomalous $t\bar{t}\gamma$ couplings in $pp \rightarrow \gamma l\nu_\ell b\bar{b}jj$ at the LHC ($\sqrt{s} = 14$ TeV) for an integrated luminosities of 30 fb^{-1} , 300 fb^{-1} , and 3000 fb^{-1} . The limits represent the maximum and minimum values obtained when taking into account the correlations between any possible pair of anomalous couplings.

coupling	30 fb^{-1}	300 fb^{-1}	3000 fb^{-1}
ΔF_{1V}^γ	+0.23 -0.14	+0.079 -0.045	+0.037 -0.019
ΔF_{1A}^γ	+0.17 -0.52	+0.051 -0.077	+0.018 -0.024
ΔF_{2V}^γ	+0.34 -0.35	+0.19 -0.20	+0.12 -0.12
ΔF_{2A}^γ	+0.35 -0.36	+0.19 -0.21	+0.11 -0.14

Single Top+ γ

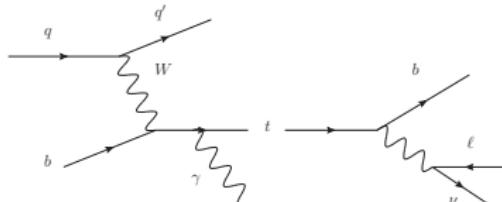
Search for the top $g - 2$ in single-top+ γ production (t-channel):

$$pp \rightarrow b j \ell^+ \nu_\ell \gamma$$

with $\ell = e, \mu$.

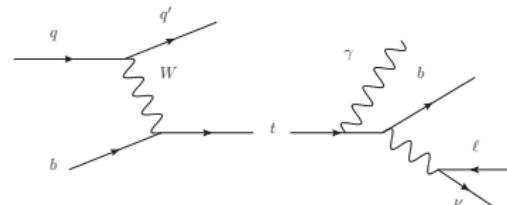
Radiative production:

$$pp \rightarrow (t \rightarrow b \ell^+ \nu_\ell) j \gamma$$



Radiative radiative decay:

$$pp \rightarrow (t \rightarrow b \ell^+ \nu_\ell \gamma) j$$

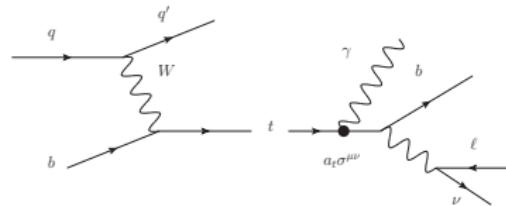
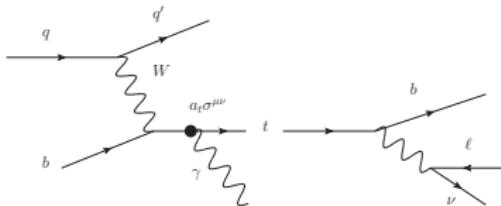


Main source of background $pp \rightarrow jj\gamma$ ($W \rightarrow \ell\nu_\ell$), one of the two light jet is mistagged as a b -jet.

General Top Interactions in MG5

- Simulation of parton-level events at LHC@14TeV with *MadGraph5*.
- Implementation of the general top anomalous interactions in MadGraph5 via the Mathematica package *FeynRules*.

$\mathcal{L}_{\text{eff}} \longrightarrow \text{FeynRules} \longrightarrow \text{NewModel.UFO} \longrightarrow \text{MadGraph5}$



- Optimal cuts
- Study of possible angular correlation induced by the anomalous couplings.



Monte Carlo Simulation

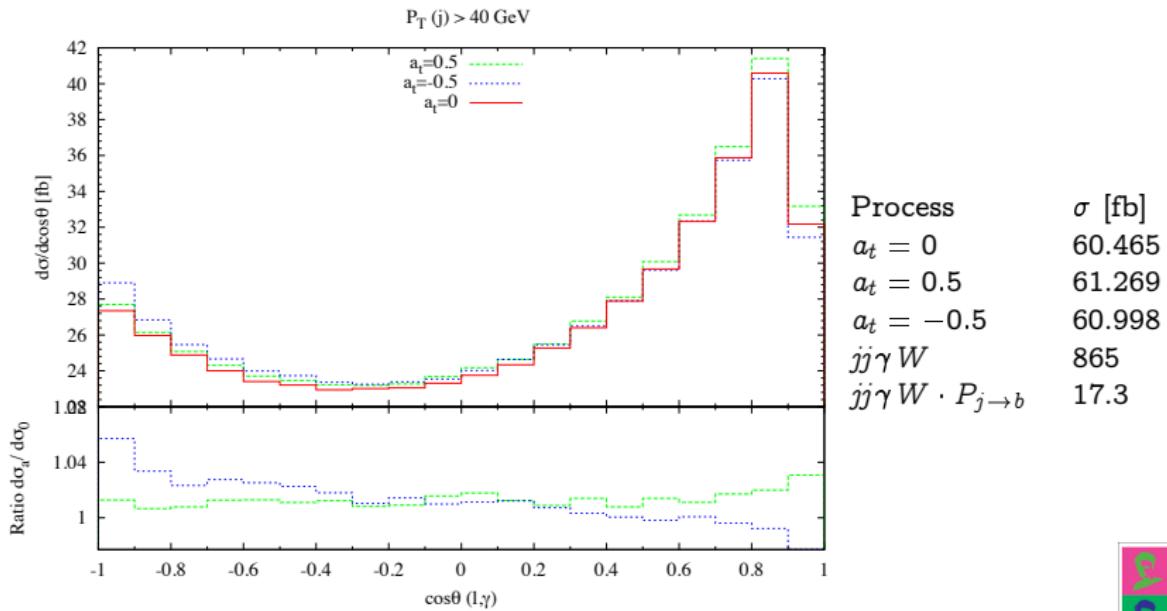
- Signal and backgrounds are generated using MG/ME v.5.1. PDF set CTEQ6L1. Fixed $\mu_R = \mu_F = m_t$.
- Cuts:

$p_T(j) > 40$ GeV, $p_T(b) > 40$ GeV, $p_T(\gamma) > 30$ GeV, $p_T(\ell) > 20$ GeV, $\not{p}_T > 20$ GeV;

$|\eta(j)| < 5.0$, $|\eta(b, \ell, \gamma)| < 2.5$, $\Delta R_{ab} > 0.4$, $a, b = j, b, \ell, \gamma$, $m_T(\ell\gamma, \not{p}_T) > 90$ GeV.



Basic Cuts



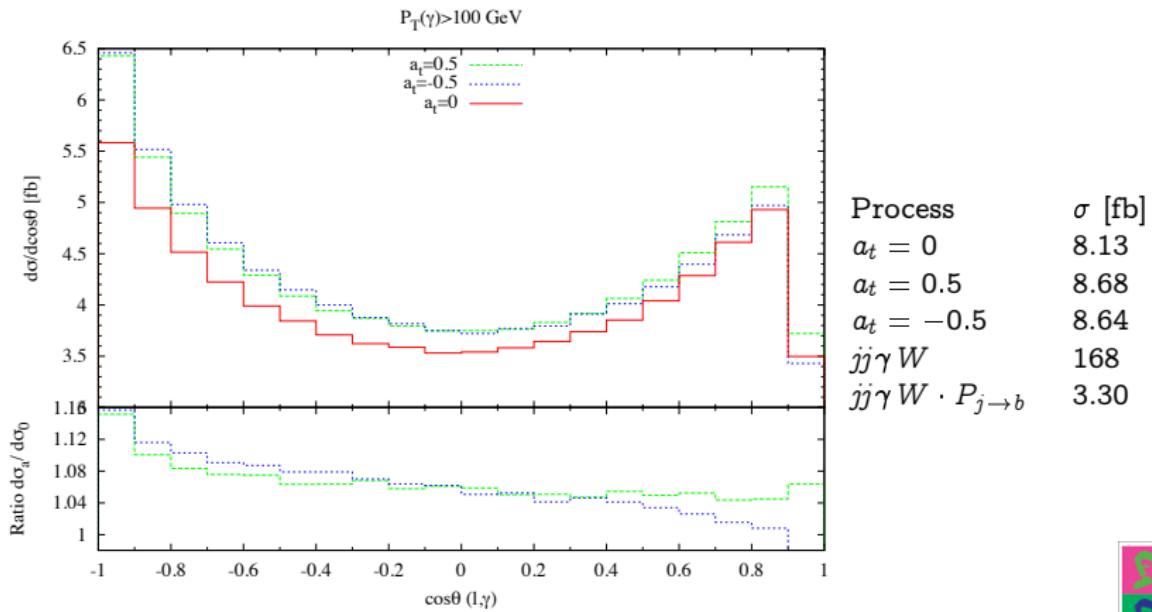
Cuts:

$p_T(j) > 40$ GeV, $p_T(b) > 40$ GeV, $p_T(\gamma) > 100$ GeV, $p_T(\ell) > 20$ GeV, $\not{p}_T > 20$ GeV;

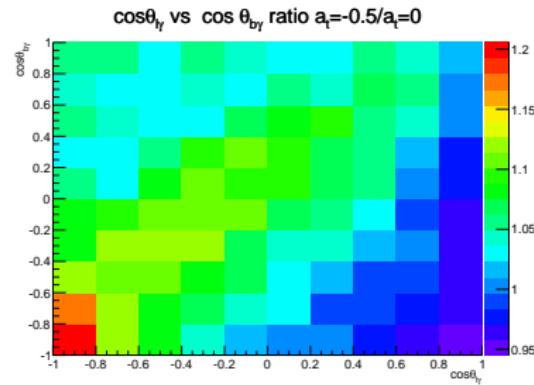
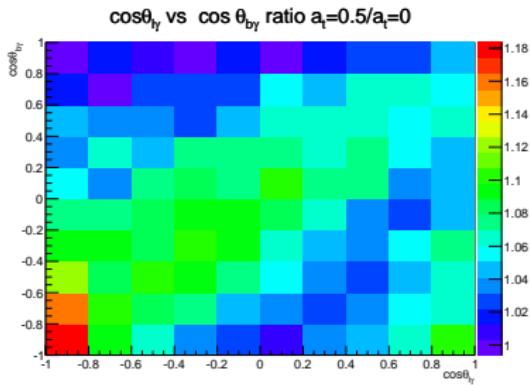
$$|\eta(j)| < 5.0, \quad |\eta(b, \ell, \gamma)| < 2.5,$$

$$\Delta R_{ab} > 0.4, \quad a, b = j, b, \ell, \gamma, \quad m_T(\ell\gamma, \not{p}_T) > 90 \text{ GeV}.$$



$p_t(\gamma) > 100 \text{ GeV}$ 

$p_t(\gamma) > 100 \text{ GeV}$



Top Quark Candidate

- Top-quark candidate through the reconstruction of the W boson.
- Apply the W-mass constraint in order to extract the z component ν_z :

$$M_W^2 = \left(E_\ell + \sqrt{\cancel{E}_T + \nu_z} \right)^2 + (\mathbf{P}_{T,\ell} + \cancel{\mathbf{E}}_T)^2 + (P_{z,\ell} + \nu_z)^2$$

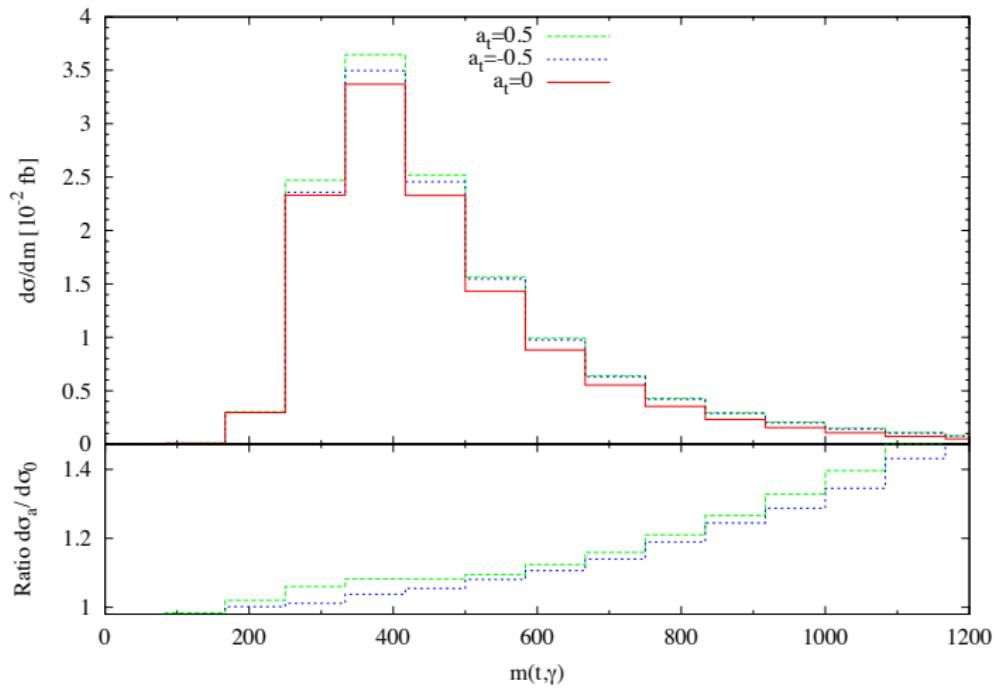
- If solutions are complex, the component of the missing energy are modified such to give $M_T(\ell, \cancel{E}_T) = M_W$.
- Two solutions: $\nu_{y1,2}(\nu_x)$
- The distance δ between the transverse momentum of the neutrino and the missing transverse energy is minimized:

$$\delta_{1,2}(\nu_x) = \sqrt{(\nu_x - \cancel{E}_x)^2 + (\nu_{y1,2}(\nu_x) - \cancel{E}_y)^2}$$

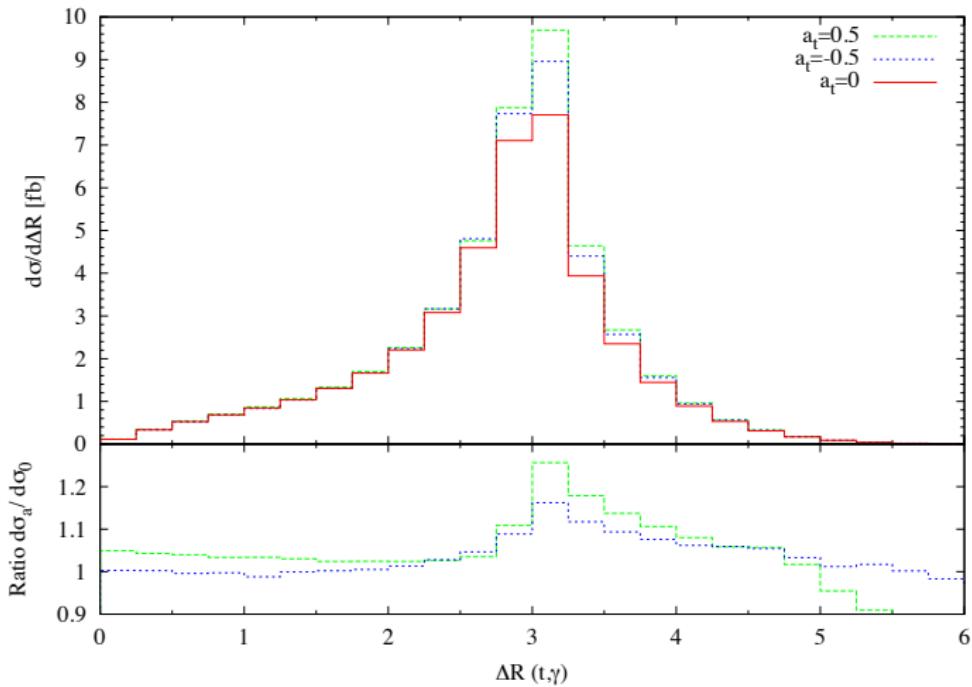
The solution with the minimum δ is chosen.



$pt(\gamma) > 100 \text{ GeV}$



$pt(\gamma) > 100 \text{ GeV}$



Summary and Outlook

- Search for top quark $g - 2$ at LHC.
- Construction of the effective Lagrangian for the top anomalous coupling.
- Bounds from $t\bar{t}\gamma$: $-0.20 \leq \Delta F_{2V}^\gamma \leq +0.19$ with 300 fb^{-1} at LHC@14TeV.
- Study of single-top+ γ .
- Implementation in MG5 via the Mathematica package FeynRules. MonteCarlo simulation of signal at parton level in MG5.
- Optimization of cuts.
- Background effects.
- Quantitative bounds on a_t from single-top+ γ production.



Thanks!



The acceptance cuts for $\gamma\ell\nu_\ell b\bar{b}jj$ events at the LHC are

$$\not{p}_T > 20 \text{ GeV},$$

$$p_T(b) > 20 \text{ GeV}, \quad |\eta(b)| < 2.5, \quad \Delta R(b, b) > 0.4,$$

$$p_T(j) > 20 \text{ GeV}, \quad |\eta(j)| < 2.5, \quad \Delta R(j, j) > 0.4, \quad \Delta R(j, b) > 0.4,$$

$$p_T(\gamma) > 30 \text{ GeV}, \quad |\eta(\gamma)| < 2.5, \quad \Delta R(\gamma, j) > 0.4, \quad \Delta R(\gamma, b) > 1.0,$$

$$p_T(\ell) > 15 \text{ GeV}, \quad |\eta(\ell)| < 2.5, \quad \Delta R(\ell, \gamma) > 0.4, \quad \Delta R(\ell, j) > 0.4, \quad \Delta R(\ell, b) > 0.4$$

$$m(jj\gamma) > 90 \text{ GeV} \quad \text{and} \quad m_T(\ell\gamma; \not{p}_T) > 90 \text{ GeV},$$

$$m_T^2(\ell\gamma; \not{p}_T) = \left(\sqrt{\not{p}_T^2(\ell\gamma) + m^2(\ell\gamma)} + \not{p}_T \right)^2 - \left(\vec{p}_T(\ell\gamma) + \vec{p}_T \right)^2,$$

$$m_T(b_{1,2}\ell; \not{p}_T) < m_t + 20 \text{ GeV} \quad \text{and} \quad m_t - 20 \text{ GeV} < m(b_{2,1}jj) < m_t + 20 \text{ GeV},$$

$$m_T(b_{1,2}\ell\gamma; \not{p}_T) < m_t + 20 \text{ GeV} \quad \text{and} \quad m_t - 20 \text{ GeV} < m(b_{2,1}jj) < m_t + 20 \text{ GeV},$$

or

$$m_T(b_{1,2}\ell; \not{p}_T) < m_t + 20 \text{ GeV} \quad \text{and} \quad m_t - 20 \text{ GeV} < m(b_{2,1}jj\gamma) < m_t + 20 \text{ GeV}$$

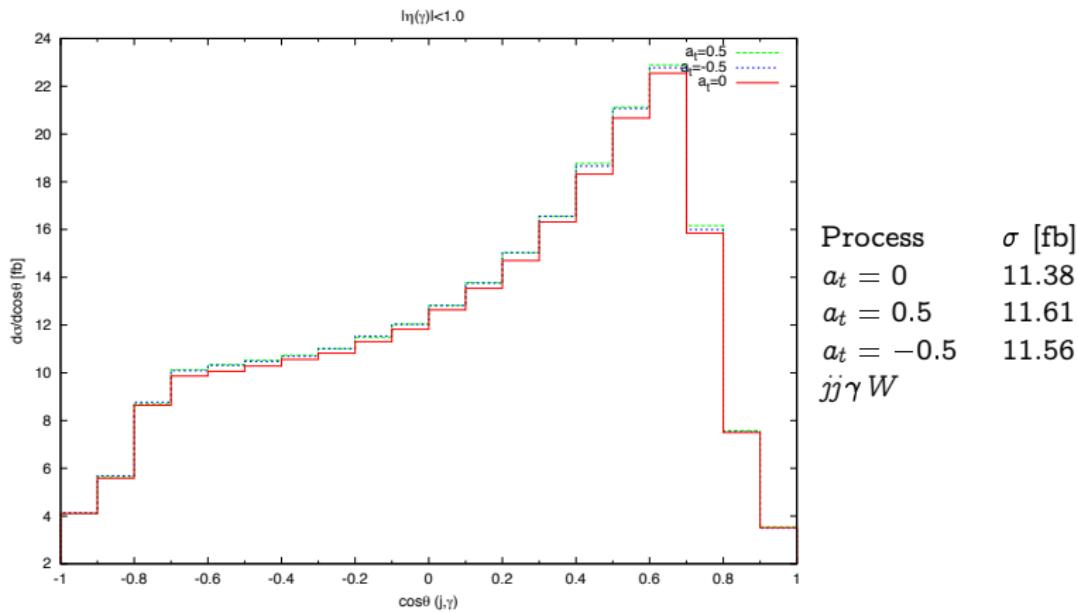
$$\sigma(pp \rightarrow t\bar{t}\gamma \rightarrow \gamma\ell\nu_\ell b\bar{b}jj) = 82 \text{ fb}$$

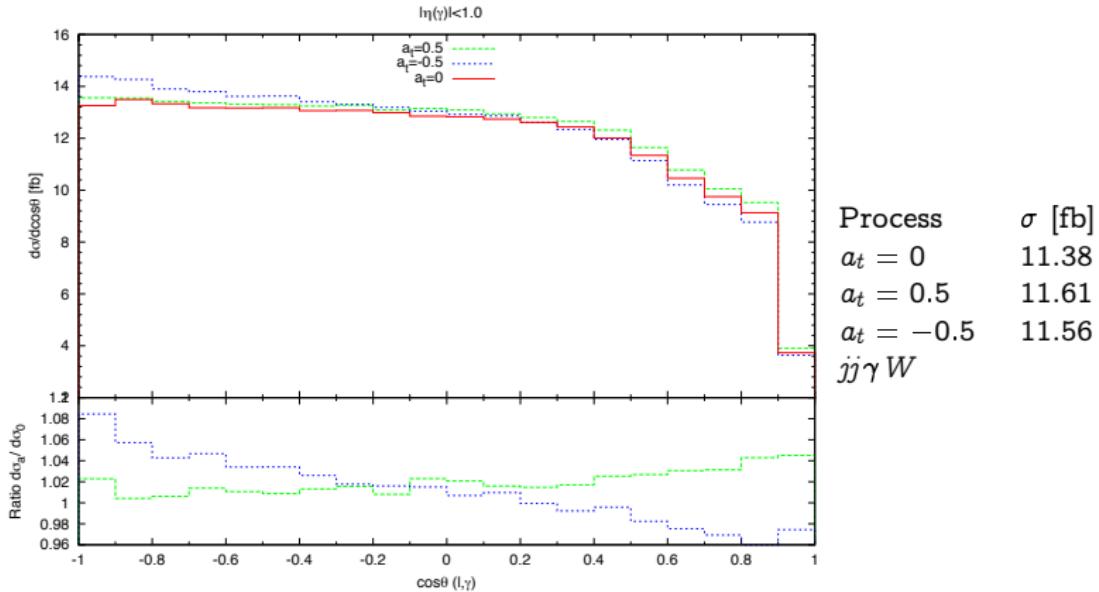
Cuts:

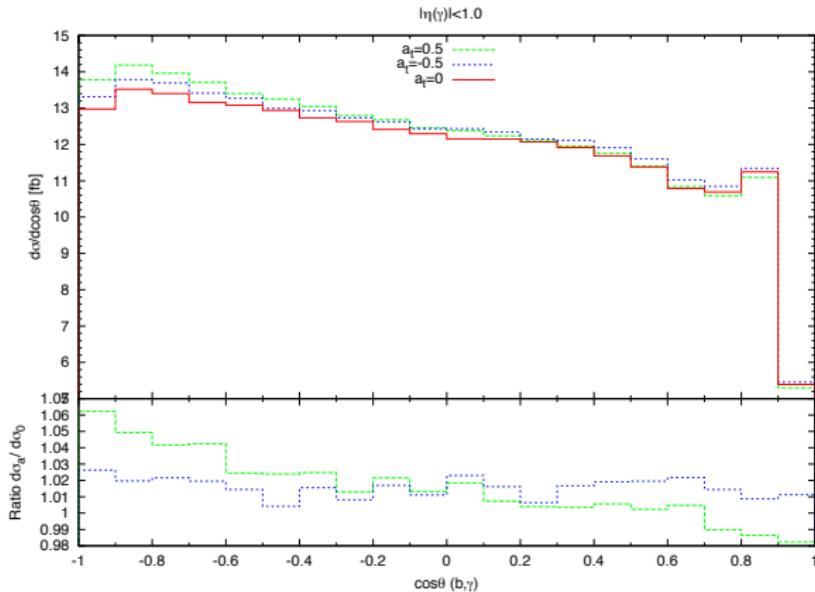
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$|\eta(j)| < 5.0$, $|\eta(b, \ell)| < 2.5$, $|\eta(\gamma)| < 1.0$,

$\Delta R_{ab} > 0.4$, $a, b = j, b, \ell, \gamma$, $m_T(\ell\gamma, \not{p}_T) > 90 \text{ GeV}$.







Process	σ [fb]
$a_t = 0$	11.38
$a_t = 0.5$	11.61
$a_t = -0.5$	11.56
$jj\gamma W$	



